Automatic feature extraction of waveform signals for in-process diagnostic performance improvement

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In this paper, a new methodology is presented for developing a diagnostic system using waveform signals with limited or with no prior fault information. The key issues studied in this paper are automatic fault detection, optimal feature extraction, optimal feature subset selection, and diagnostic performance assessment. By using this methodology, a diagnostic system can be developed and its performance is continuously improved as the knowledge of process faults is automatically accumulated during production. As a real example, the tonnage signal analysis for stamping process monitoring is provided to demonstrate the implementation of this methodology.

Keywords: Automatic feature extraction, Haar transform, waveform signals, process monitoring, fault diagnosis

1. Introduction

Monitoring and diagnostic systems have played an important role in modern manufacturing process control. Many intelligent or knowledge-based systems have been successfully developed for different application domains. However, the development of such a system normally requires sufficient prior knowledge or fault condition data, which is hard to satisfy in manufacturing systems. This is especially true for a new product or process launch. Thus, the motivation of the research presented in this paper is to address this important issue by developing a methodology for monitoring and diagnostic system development with limited or with no prior fault information. Waveform signals are used as the essential information for the diagnostic system development.

Waveform signals represent a class of analog or digital signals over time, which normally can be measured using in-process sensors in a manufacturing process. It has broad potential applications, such as tonnage signals in stamping, torque signals in tapping, and force signals in welding, which are shown in Fig. 1 (a)–(c), respectively. In general, those waveform signals contain rich information that can be related to both product quality and process variables. The characteristics of those waveform signals studied in this paper are summarized as follows:

- Non-stationary.
- Working cycle-based signals, meaning that each cycle of a waveform signal covers a complete cycle of an operation.
- Segmental signals, meaning that different segments represent different process stages, which may have different potential process faults.
- Localized time and frequency components in different segments.
- In-process automatic sensing.
Fig. 1. Waveform signals measured in the different production processes.

There are two basic approaches in diagnostic system development by using waveform signals: a model-based approach and a feature-based approach. In the model-based approach, observations are considered as a time-ordered stochastic process. The critical concern of using this approach is to have an appropriate process model which is sensitive to process faults but robust to process noises (Deibert and Holfing, 1992). In addition, fault models or fault signal characteristics need to be known before making fault detection. However, these types of information are normally not available at the beginning of the production due to the complex relationship between waveform signals and the associated manufacturing process. Thus, a model-based approach is generally not effective when waveform signals are used for diagnostic system development.

A feature-based approach is more suitable to a complex process where waveform signals are used for process diagnosis. In such a system, features are considered as random variables or as a random set. Feature extraction and feature subset selection are critical steps to reduce the number of attributes or data dimension considered in the decision-making step (Kharin, 1992). The conventional procedure to develop a feature-based diagnostic system is shown in Fig. 2. The essential requirement, or precondition, to use this conventional procedure is that sufficient historical fault data or prior fault knowledge are available before developing a diagnostic system. In many applications, this precondition is not satisfied especially during the new machine or process launch. Therefore, it is a challenging problem to develop a feature-based diagnostic system with limited or with no prior fault information.

In this paper, we will propose an automatic feature extraction methodology for the development of a feature-based diagnostic system using waveform signals. In this methodology, the wavelet analysis is used as a basic tool for feature extraction. The wavelet analysis is selected for this research due to its multiresolution nature, its localized properties in both time and frequency domains, its fast algorithms ready for an on-line implementation, and its efficient data compression for feature extraction. The Haar transform is selected in the paper because it has an explicit geometrical interpretation for a detected change of a Haar coefficient. These interpretations can be easily associated with the profile change of a waveform signal due to process faults.

Wavelet analysis has been widely used in image and speech processing for decades. Much research has been focused on the data shrinkage and signal noise filtering (Coifman and Yale, 1992; Donoho and Johnstone, 1994). The wavelet transform used as a feature extraction method has recently received more and more attention for process monitoring in manufacturing processes, such as drill condition monitoring (Tansel et al., 1993), face milling failure

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Fig. 2. Procedures for a feature-based fault diagnosis system development.